ALI Radiometric Processing System

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Introduction

The Advanced Land Imager (ALI) was launched on the Earth Observing-1 (EO-1) platform in November of 2000, as part of NASA's New Millennium Program (NMP) to investigate new imaging technologies and data processing techniques for Earth observing sensor systems. A team at South Dakota State University in collaboration with EROS Data Center (EDC) has developed, implemented, and run a prototype radiometric processing system that performs characterization and limited 'calibration' of ALI image data. Characterization data is saved to a trending database system and is available for additional offline analyses.

This report summarizes the work that the South Dakota State University team has contributed towards this research. A brief review of the structure and operation of the radiometric processing system is presented, as is a summary of the trending process. Finally, updated results of lifetime analyses performed on the trended radiometric data are presented. These analyses generally demonstrate the continued radiometric stability of the ALI.

The EO-1 Radiometric Processing System

The EO-1 Radiometric Processing System (RPS) was developed and implemented for storing calibration data generated from ALI image data. The system possesses the capability of extracting calibration information from either Level 0 ('raw') or Level 1R (radiometrically calibrated) data sets; as currently implemented, calibration information is only extracted from raw data sets. Figure 1 shows a basic block diagram of the system. Two 'copies' of the system exist. The 'production' version of the RPS is housed at EROS Data Center, and can be run in-house or remotely from South Dakota State University. A second copy has been built at South Dakota State University, and is used primarily for development and verification of new processing modules.

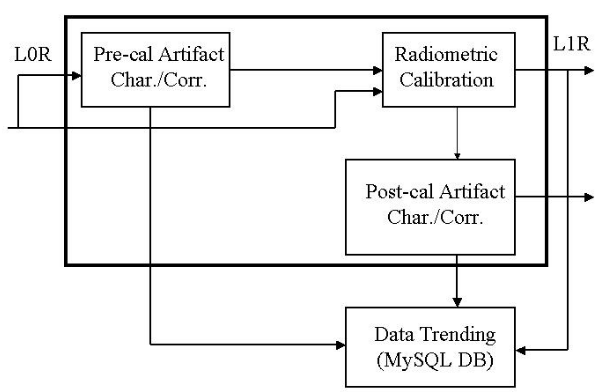

Figure 1. Radiometric Processing System Block Diagram

The design concept of the RPS and certain implementation details are similar to the Image Assessment System (IAS) that is part of the Landsat 7 ground processing system (Landsat 7 Image Assessment System Operations Concept, 1994, Landsat 7 Image Assessment System Element Specification, 1996). The RPS is currently implemented as a script-driven application that calls a series of modules programmed in C and built to run under RedHat Linux 6.2 or greater; however, the RPS is designed to be platform-independent. Maximum control over processing is available to the user simply by setting parameters in the script that represent various processing options. Expansion of system capability can be achieved by building a function module that implements the desired processing, rebuilding the entire application including the new module, and adding necessary parameters required by the new module into the script.

'Pre-calibration' characterization currently available in the RPS consists of the following:

1. 'Pre-cal' and 'Dark' bias estimation for each detector
2. Detector response to scene data (histogram statistics)
3. Detection of 'saturated' detectors
4. Detector response to the internal calibrator lamps (if lamp data is available with a scene)
5. Relative detector gain based on response to the calibrator lamps (if lamp data is available with a scene)

A capability for pre-calibration characterization on a band-average basis was accounted for in the system but not developed.

The calibration process is implemented as an individual module. It is designed to use supplied calibration coefficients for Digital Number (DN)-to-radiance conversion or relative gain adjustment. A limited framework was built into the RPS that allows it to use calibration data from other sources, i.e. solar, lunar, or vicarious, but to this date has not been further developed or tested.

As shown in Figure 1 and mentioned in the Introduction, pre- or post-calibration characterization data can be trended. All modules have been implemented with the capability to trend the processed data; trending for a given processing scenario is enabled or disabled from the script. Characterization data that is trended is stored in external databases running under MySQL, an Open Source relational database management system available for free to non-commercial applications (http://www.mysql.com). The version of MySQL used by the RPS is 3.23.38, running under RedHat Linux 6.2 or greater.

Population of Trending Databases

During the ALI's operating lifetime beginning in early 2001, the RPS has generated eleven trending databases. Nine of the databases contain detector-specific calibration data extracted from between 485 to 510 scenes. One database contains data extracted from only 402 scenes, due to an interruption in processing. The first database contains histogram statistics extracted from 463 scenes, but no bias or lamp data, due to corruption of a file containing the database's indexing information; an earlier copy contains histogram and bias/lamp data extracted from 343 scenes. Consequently, it was decided to limit the number of processed scenes trended in subsequent databases to around 500. In the later databases, this corresponds to an approximately 30-day interval in which the trended scenes were acquired. As a given day's scenes are not trended between consecutive databases, the total number of scenes contained within a given database can vary from this limit.

To date, the RPS has processed and trended calibration data from approximately 5000 scenes.

Radiometric Performance of the ALI—Update

The following sections present updated lifetime characterizations for internal calibrator lamp response and SNR performance presented by Dr. Helder at the EO1 conference in Hilo, HI in November 2002. The update covers the interval from October 2002 through February 28, 2003; the trended data was extracted from the first 9 databases. An interruption in data processing resulted in a trending gap for scenes acquired between March 1, 2003 and May 19, 2003. Processing has resumed for scenes acquired on May 20 and later; this set of trended data is contained in databases 10 and 11 (and later). Updated lifetime characterizations with a more complete set of trended data from 2003 will be presented in a subsequent report.

Bias Stability--Single Orbit Stability (Long Collect)

Bias stability over time intervals of a single scene acquisition can be determined by comparing the pre-cal and dark bias levels during long collects. Bias stability during a single scene would be indicated if the pre-cal and dark bias levels are statistically equal. The bias data sets can be assumed to meet the conditions allowing the use of T-tests to compare two sets of data.

Table 1 shows mean pre-cal and dark bias comparisons (averaged over all detectors) for a long collect acquired on day 282 during 2002 (trended in database 6). The comparisons are presented for SCA 1. The significance value indicates the likelihood of rejecting the null hypothesis of equal means between the two data sets. Values close to 1.0 indicate no statistically significant differences, while values close to 0.0 indicate statistically significant differences.

Table 1. EO12002282175532_PF1_01 Long Collect Bias Check, SCA 1

BAND	PRE-CAL (DN)	DARK (DN)	% DIFF	T-TEST	SIGNIFICANCE
MS-1p	246.73 +- 15.81	246.79 +- 15.81	-0.025	-0.05	0.96
MS-1	257.89 +- 13.69	257.84 +- 13.69	0.02	0.05	0.96
MS-2	263.17 +- 14.42	263.14 +- 14.42	0.013	0.03	0.98
MS-3	268.90 +- 15.33	268.89 +- 15.32	0.0015	0.003	1.00
MS-4	256.29 +- 11.82	256.33 +- 11.82	-0.015	-0.04	0.97
MS-4p	252.65 +- 14.07	252.74 +- 14.11	-0.04	-0.09	0.94
MS-5p	662.06 +- 127.58	656.31 +- 126.78	0.87	0.57	0.57
MS-5	374.49 +- 71.84	371.41 +- 71.59	0.82	0.54	0.59
MS-7	721.46 +- 213.76	715.13 +- 215.90	0.88	0.37	0.71

These results continue to demonstrate excellent bias stability over the interval of a single scene acquisition, with estimated pre-cal and dark bias levels differing by less than 1% for all bands in SCA1. The most significant variation between pre-cal and dark bias levels was consistently observed to occur in bands 5p and 7 for all SCA's, as shown in Table 2. All differences in bias levels were less than 2%.

Table 2. EO12002282175532_PF1_01 Long Collect Bias Check, Bands 5p and 7, All SCAs

SCA/BAND	PRE-CAL (DN)	DARK (DN)	% DIFF	T-TEST	SIGNIFICANCE
1, MS-5p	662.06 +- 127.58	656.31 +- 126.78	0.87	0.57	0.57
1, MS-7	721.46 +- 213.76	715.13 +- 215.90	0.88	0.37	0.71
2, MS-5p	650.56 +- 358.23	642.37 +- 357.80	1.26	0.29	0.77
2, MS-7	670.39 +- 137.83	658.15 +- 134.74	1.83	1.14	0.25
3, MS-5p	249.18 +- 66.75	249.87 +- 64.44	-0.28	-0.13	0.89
3, MS-7	227.86 +- 124.69	226.15 +- 122.17	0.75	0.18	0.86
4, MS-5p	408.79 +- 137.89	408.25 +- 136.31	0.13	0.05	0.96
4, MS-7	593.11 +- 234.30	586.85 +- 234.19	1.05	0.34	0.74

Bias Stability—Lifetime Stability

Updated plots of the band-averaged lifetime pre-cal and dark bias response for SCA 1, band MS-1p are shown in Figures 1a and 1b. These plots have been 'filtered' to eliminate 16 scenes in the pre-cal data set that exhibited 'outlier' values ranging from 0 to around 915 and sixteen scenes exhibiting 0 dark response. As observed in previous analyses, two 'states' in bias response can be seen.

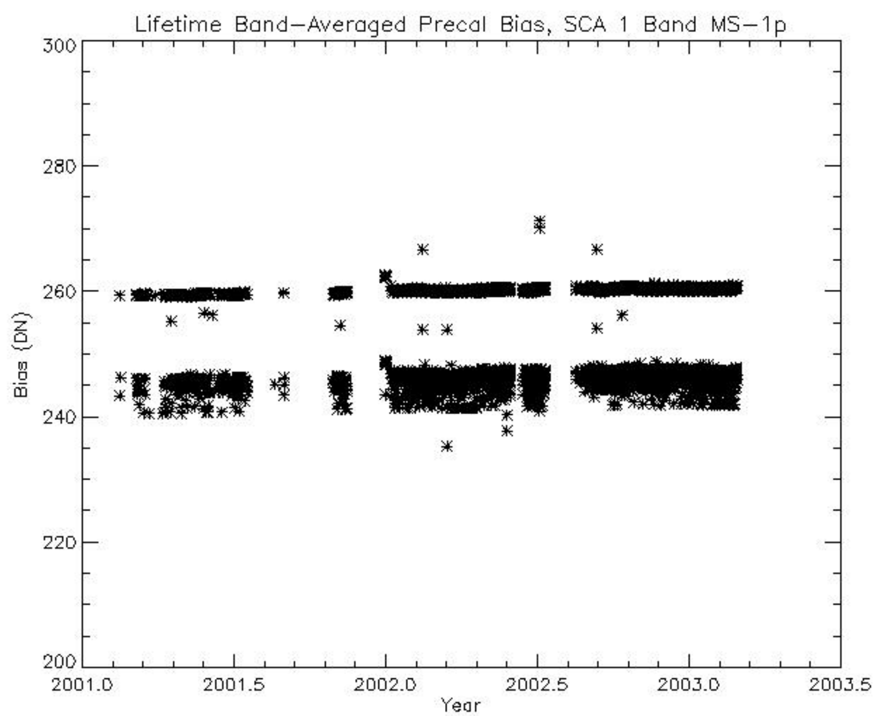

Figure 1a. Lifetime Precal Bias, SCA 1, Band MS-5p

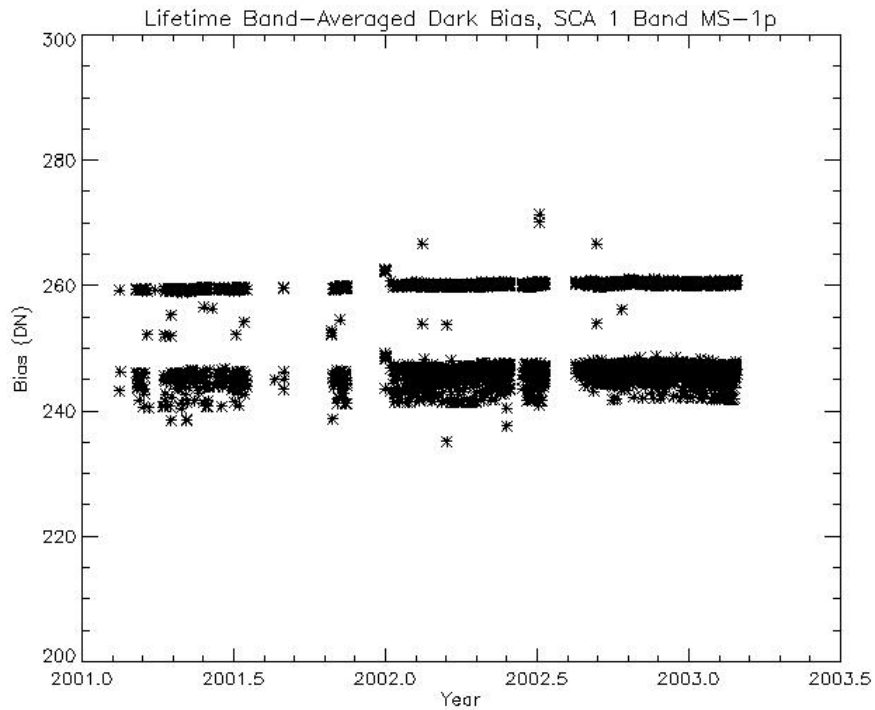

Figure 1b. Lifetime Dark Bias, SCA 1 Band MS-5p

Table 3 gives a T-test comparison between the pre-cal and dark bias data. A statistically significant difference in response was observed; however, the difference in mean lifetime response between the pre-cal and dark bias levels was less than 1 count.

Table 3. Pre-cal/Dark Lifetime Bias Comparison, SCA 1, Band MS-1p

MEAN PRE-CAL BIAS (DN)	MEAN DARK BIAS (DN)	% DIFF	T-TEST	SIGNIFICANCE
253.45 +- 11.48	252.93 +- 7.31	0.21	2.49	0.013

These results tend to confirm the good lifetime stability between pre-cal and dark bias levels observed in previous analyses.

Figures 1c-1f show the band-averaged lifetime pre-cal and dark bias responses for SCA 1, bands MS-5p and MS-7, respectively. Contamination effects are clearly evident in both bands, particularly during late 2002 through 2003, when the outgassing interval was increased. Modeling of these phenomena will be included with analysis of an extended lifetime data set and presented in a future report.

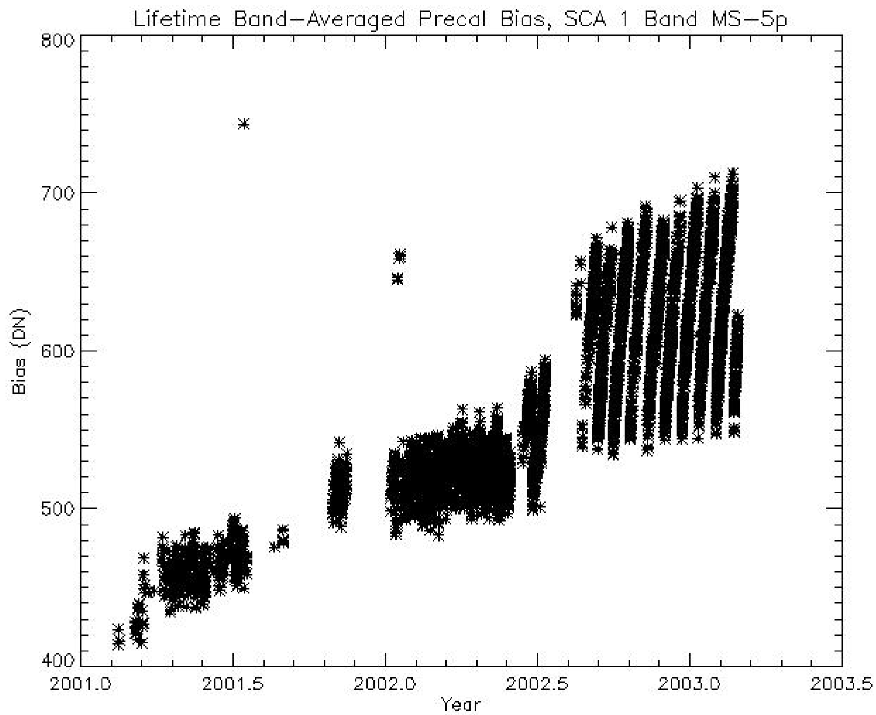

Figure 1c. Band-averaged Lifetime Precal Bias, SCA 1, Band MS-5p

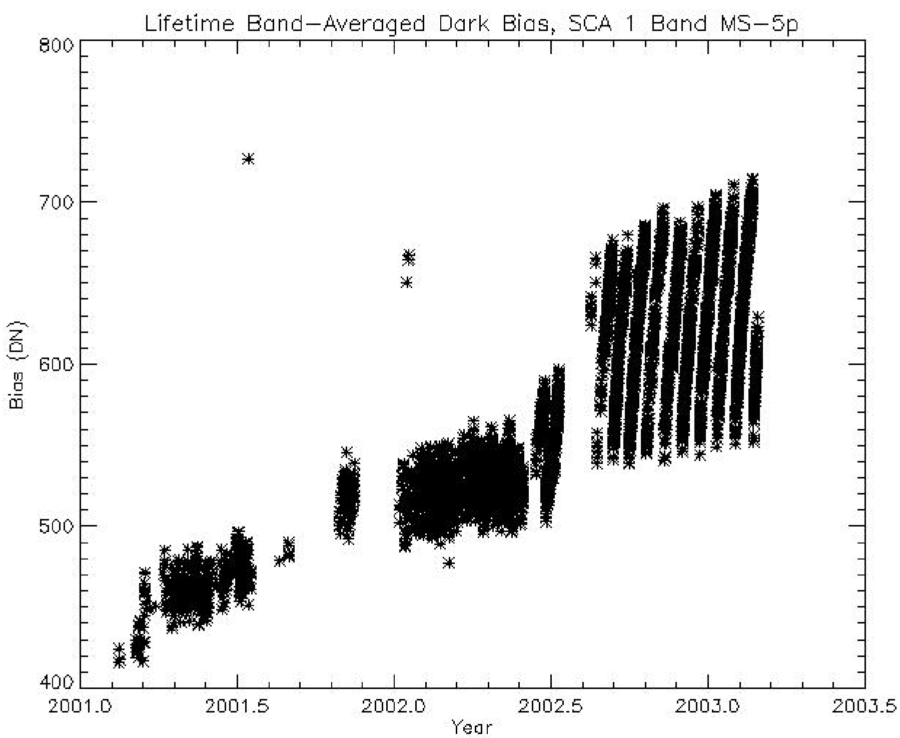

Figure 1d. Band-averaged Lifetime Dark Bias, SCA 1, Band MS-5p

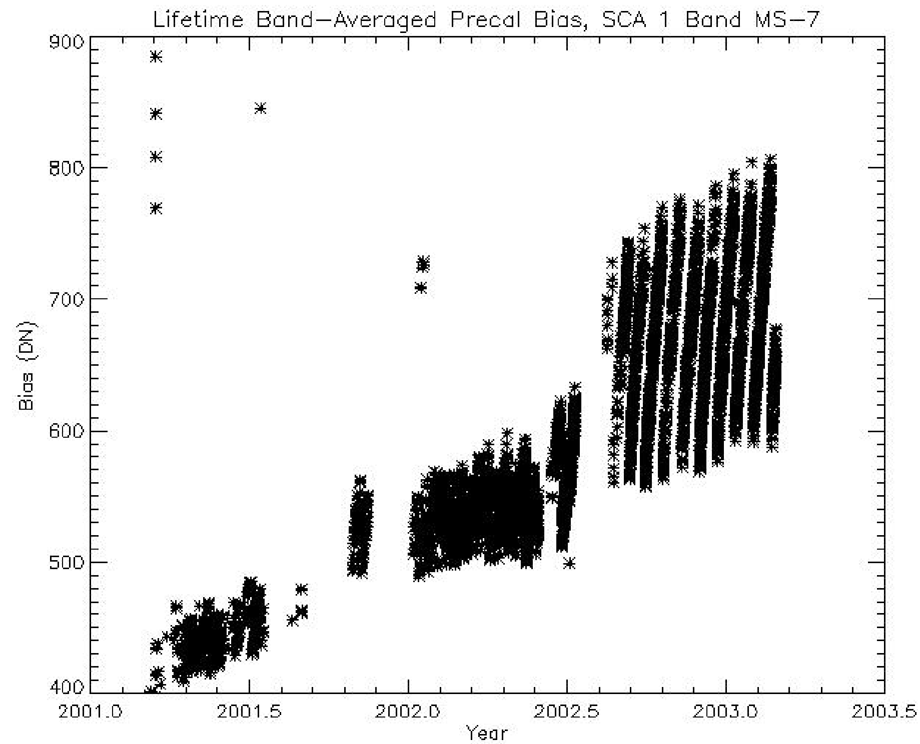

Figure 1e. Band-averaged Lifetime Precal Bias, SCA 1, Band MS-7

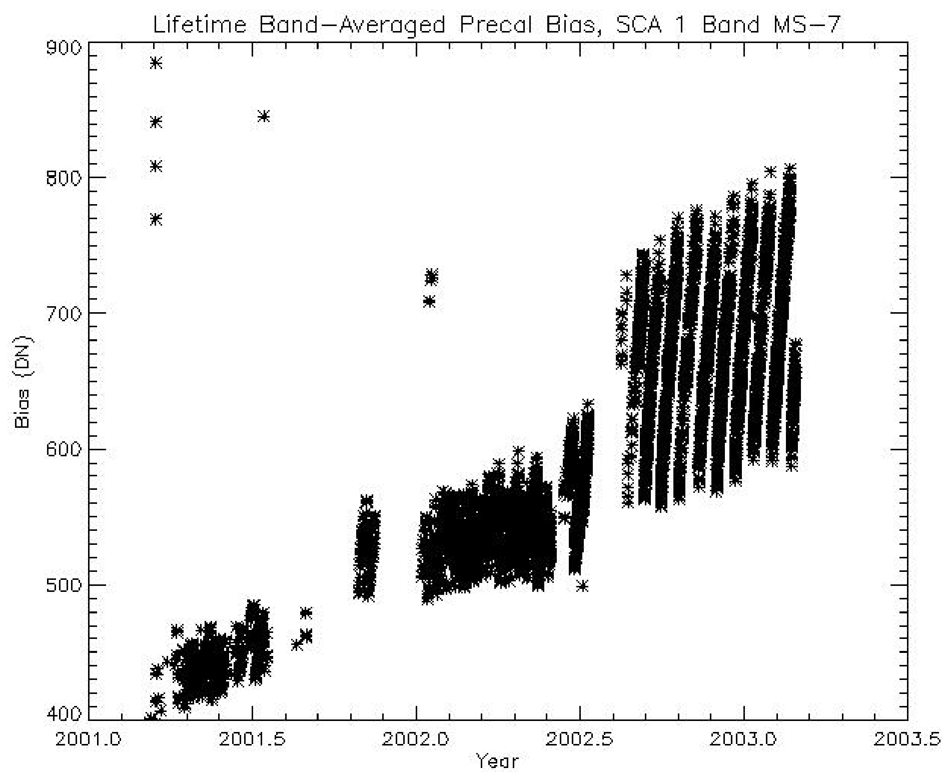

Figure 1f. Band-averaged Lifetime Dark Bias, SCA 1, Band MS-7

Lamp Stability

Updated plots showing the lifetime lamp stability for each band are shown in Figures 1a through 1i in Section A.1 of the Appendix. Table 4 compares the updated changes in lamp DN/yr for each band from SCA's 1 and 4 with the same changes from the previous analysis period, which ended in October 2002.

Table 4. Change In Band-Averaged Lifetime Lamp Response, LS 1

SCA/BAND	Period Ending Oct 2002 (DN)	Period Ending Feb 2003 (DN)	% Difference
1, MS-1p	42.62	42.49	-0.31
1, MS-1	68.44	68.37	-0.10
1, MS-2	242.86	242.72	-0.06
1, MS-3	685.84	684.26	-0.23
4, MS-4	1835.36	1826.82	-0.47
4, MS-4p	1952.02	1951.14	-0.05
4, MS-5p	516.01	512.83	-0.62
4, MS-5	1389.86	1389.89	0.0022
4, MS-7	1825.77	1815.65	-0.55

Based on these results, it is apparent that all bands are maintaining stability in their lamp response, with mean values changing less than 1% in a 6-month period.

SNR Stability

Updated plots showing the lifetime SNR stability for each band are shown in Figures 2a through 2i in Section A.2 of the Appendix. Table 5 shows the estimated changes in SNR/yr for each band from SCA's 1 and 4 with the same changes from the previous analysis period ending in October 2002.

Table 5. Change in Lifetime Band-Averaged SNR, LS 1

SCA/BAND	Period Ending Oct 2002	Period Ending Feb 2003	% Difference
1, MS-1p	47.13	47.18	0.11
1, MS-1	86.03	86.06	0.035
1, MS-2	282.64	282.78	0.05
1, MS-3	608.01	607.83	-0.03
4, MS-4	818.01	813.37	-0.57
4, MS-4p	804.76	799.83	-0.61
4, MS-5p	472.80	461.52	-2.39
4, MS-5	1122.61	1115.01	-0.68
4, MS-7	968.63	949.50	-1.97

Based on these results, it is apparent that the VNIR bands and the SWIR band 5 are maintaining their SNR stability, changing less than 1% over a 6-month period. Bands 5p and 7 appear to be drifting the most in terms of SNR stability over a 6-month interval; the SNR for band 5p appears to have decreased about 2.4%, while band 7 appears to have decreased around 2%.

Conclusions

This report has presented a brief summary update of lifetime characterization results for the ALI from early 2001 through February 2003. The results demonstrate the usefulness of the RPS system for trending instrument performance and the continued radiometric stability of the instrument in terms of overall lamp response and signal SNR.

Appendix

This appendix contains updated plots for lifetime response and SNR performance due to lamp state 1 for all bands in SCA's 1 and 4.

A.1 Lamp Stability

Figures A1a-A1i show the band-averaged net lifetime response to lamp state 1 (corresponding to all lamps on) for each multispectral band taken from SCA's 1 and 4. In these plots, the green error bars represent the standard deviation from the mean lamp value for every 40th scene.

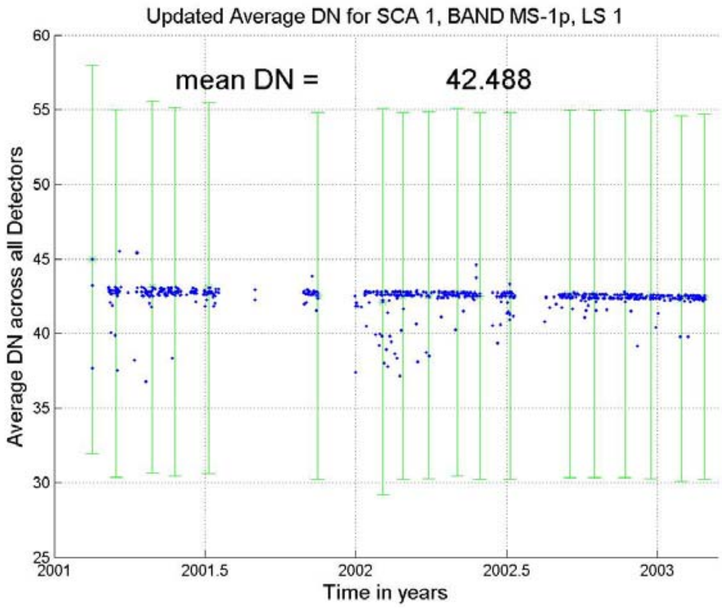

Figure A1a. Lifetime Lamp Response, SCA 1 Band MS-1p, LS 1

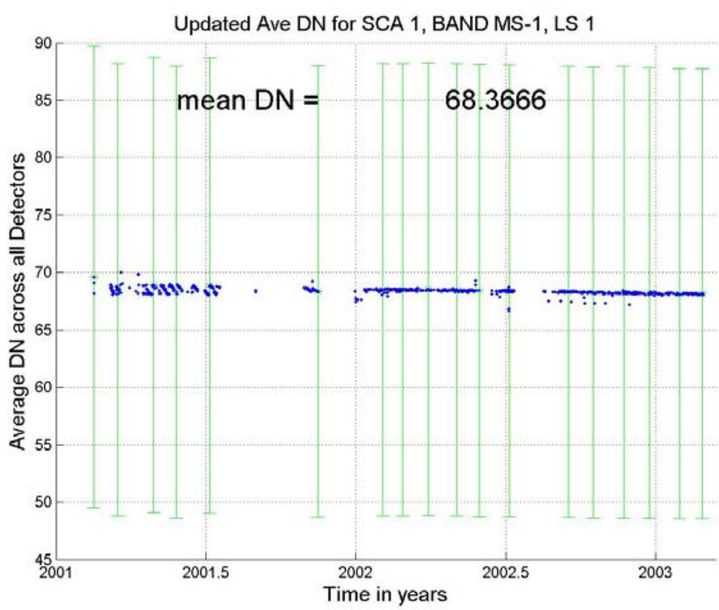

Figure A1b. Lifetime Lamp Response, SCA 1 Band MS-1, LS 1

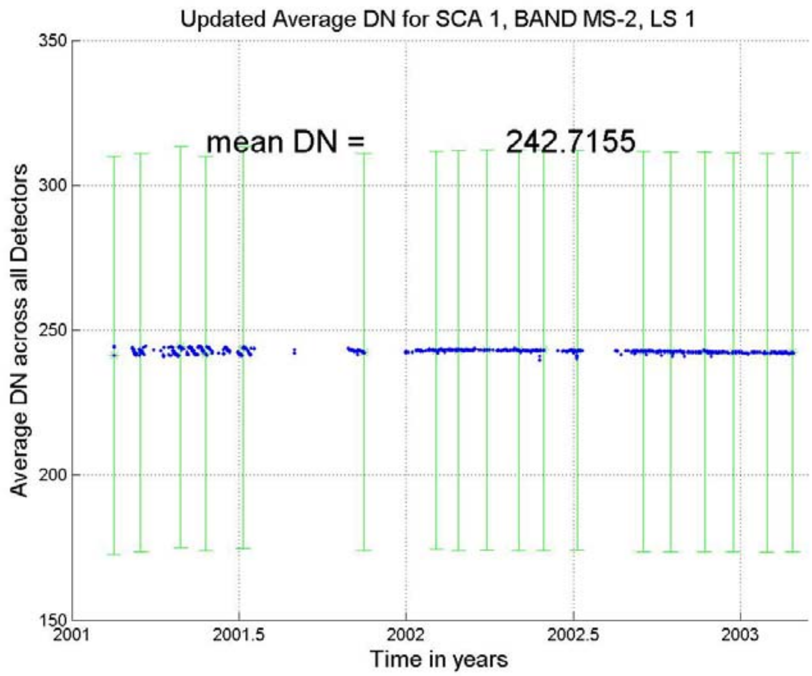

Figure A1c. Lifetime Lamp Response, SCA 1 Band MS-2, LS 1

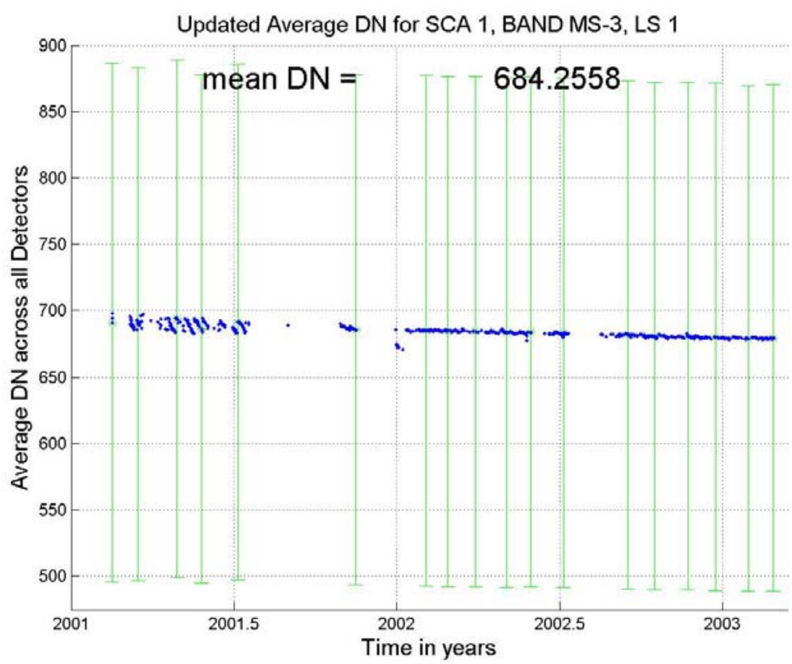

Figure A1d. Lifetime Lamp Response, SCA 1 Band MS-3, LS 1

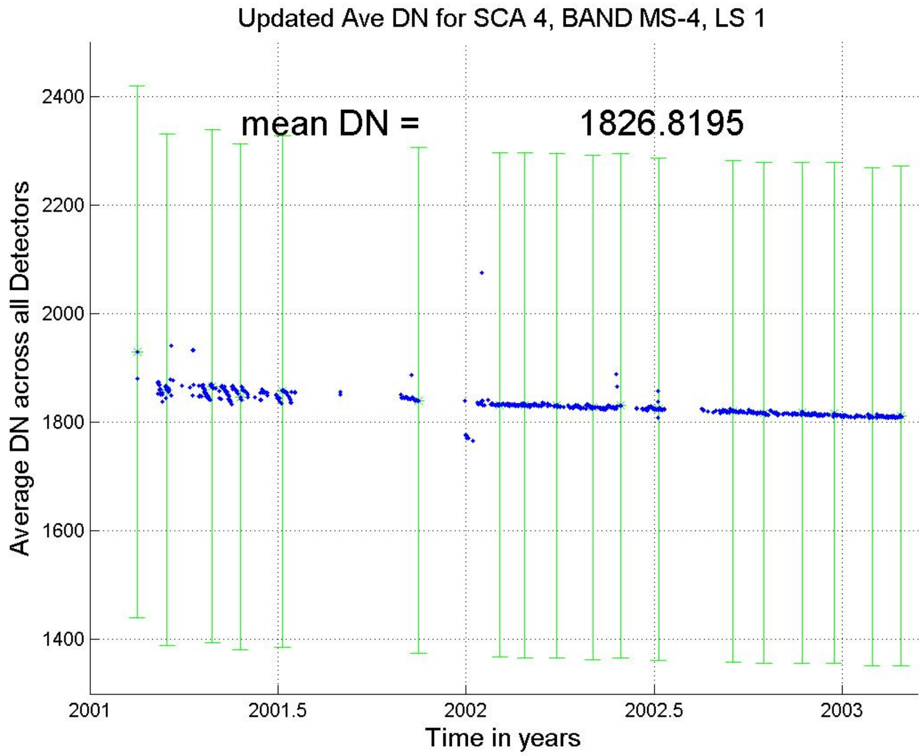

Figure A1e. Lifetime Lamp Response, SCA 4 Band MS-4, LS 1

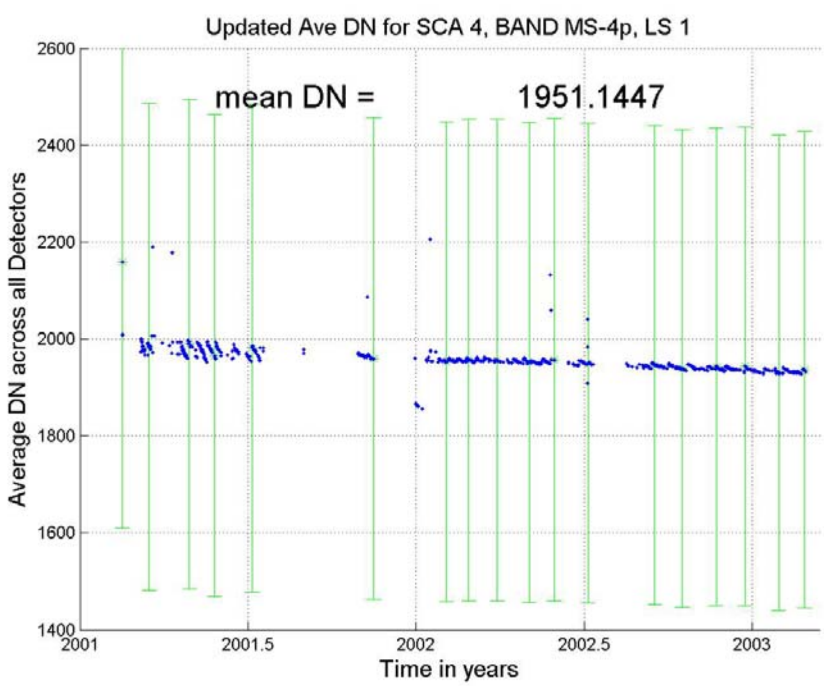

Figure A1f. Lifetime Lamp Response, SCA 4 Band MS-4p, LS 1

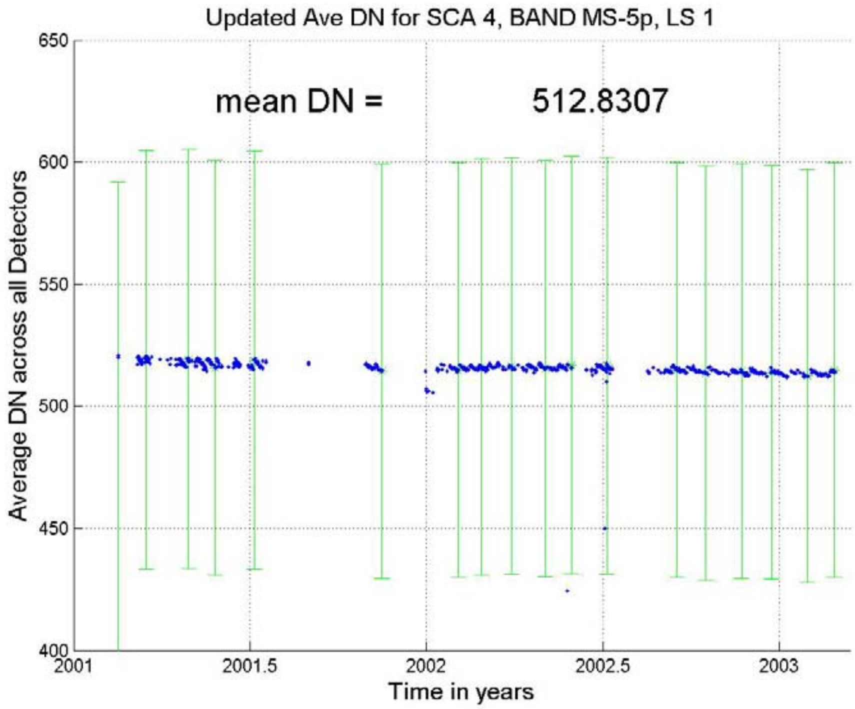

Figure A1g. Lifetime Lamp Response, SCA 4 Band MS-5p, LS 1

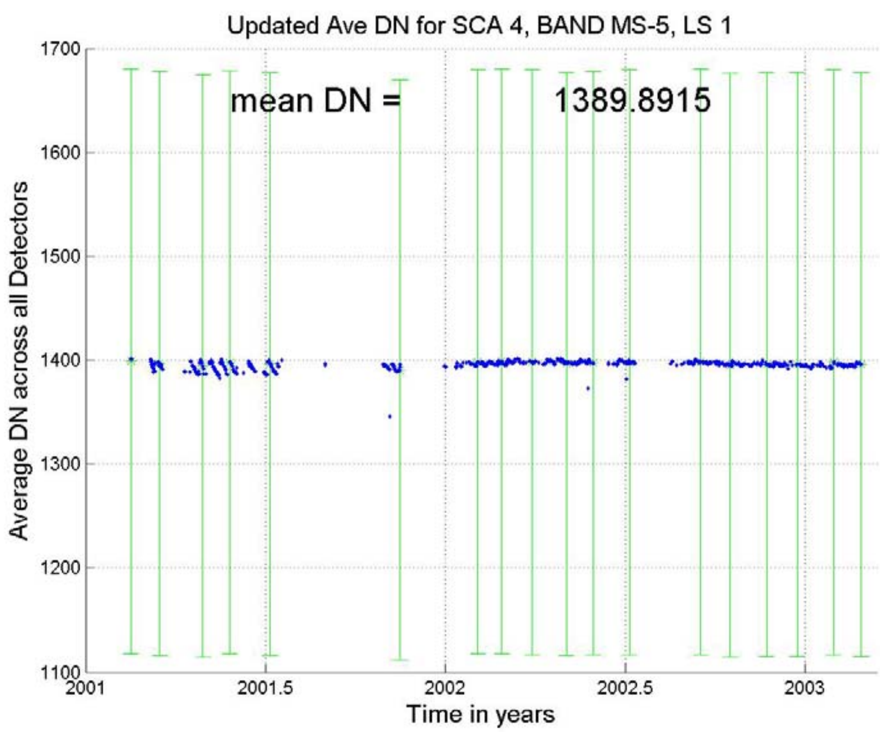

Figure A1h. Lifetime Lamp Response, SCA 4 Band MS-5, LS 1

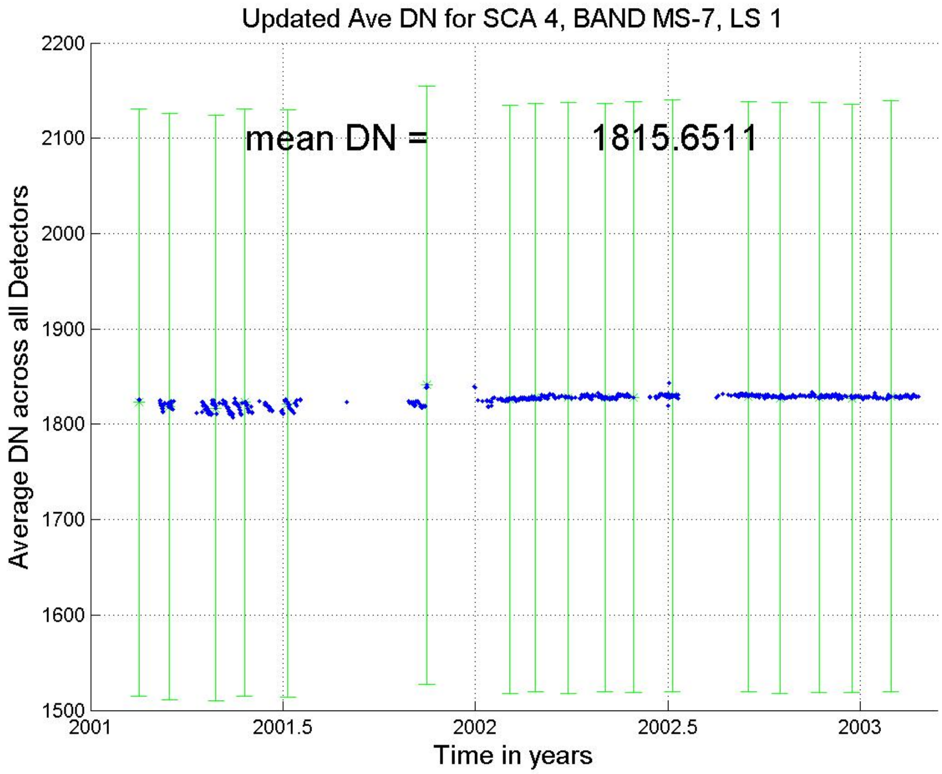

Figure A1i. Lifetime Lamp Response, SCA 4 Band MS-7, LS

A.2 SNR Stability

Figures A2a-A2i show the mean lifetime SNR for each multispectral band. SNR estimates for bands MS-1p through MS-3 are taken from SCA 1, and estimates for bands MS-4 through MS-7 are taken from SCA 4. All SNR estimates shown were determined for lamp state 1 (all lamps on). Again, the green error bars represent the variation around the mean SNR value for every 40th scene.

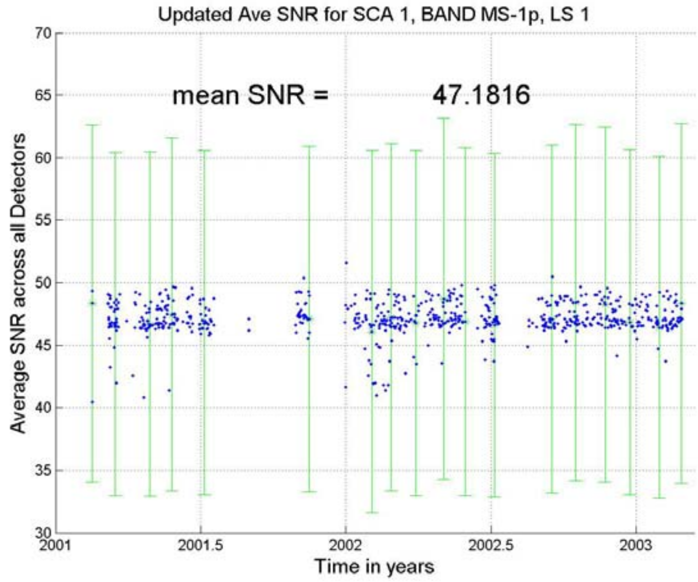

Figure A2a. Lifetime SNR, SCA 1 Band MS-1p, LS 1

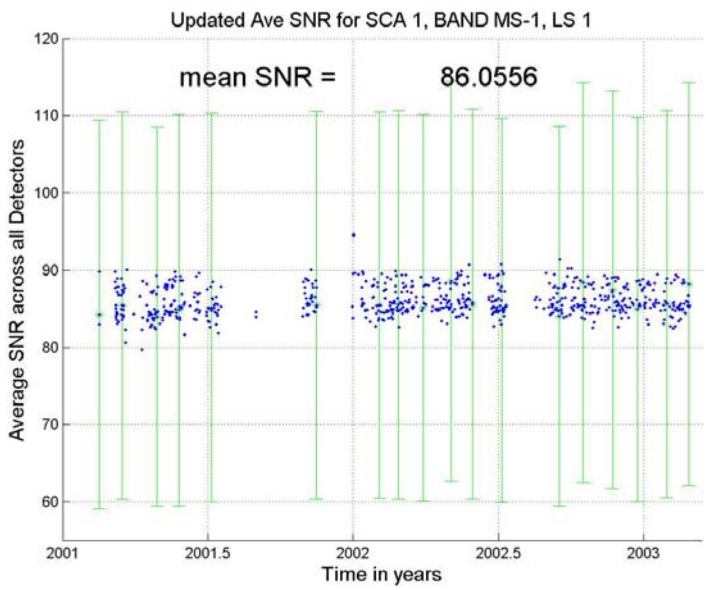

Figure A2b. Lifetime SNR, SCA 1 Band MS-1, LS 1

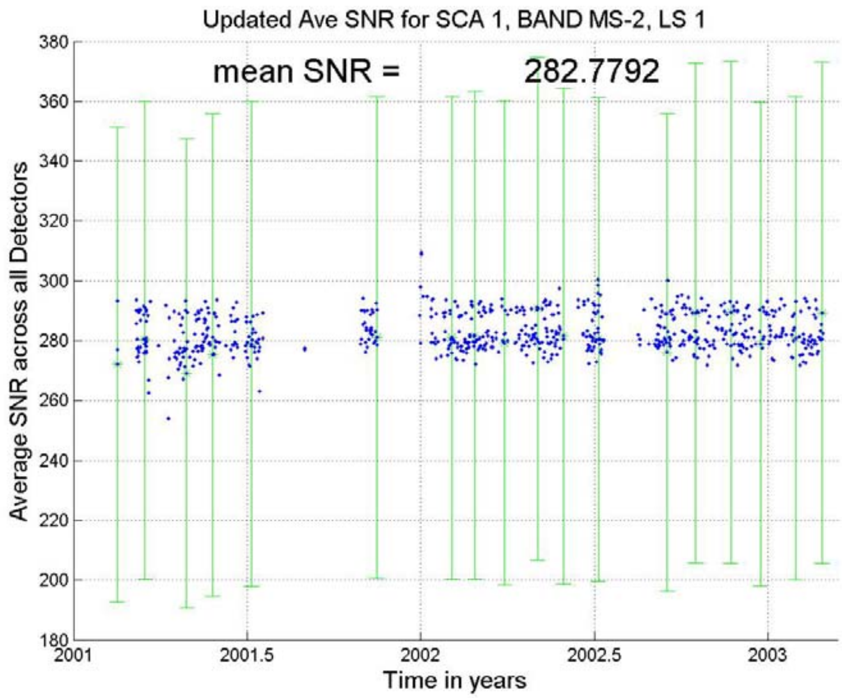

Figure A2c. Lifetime SNR, SCA 1 Band MS-2, LS 1

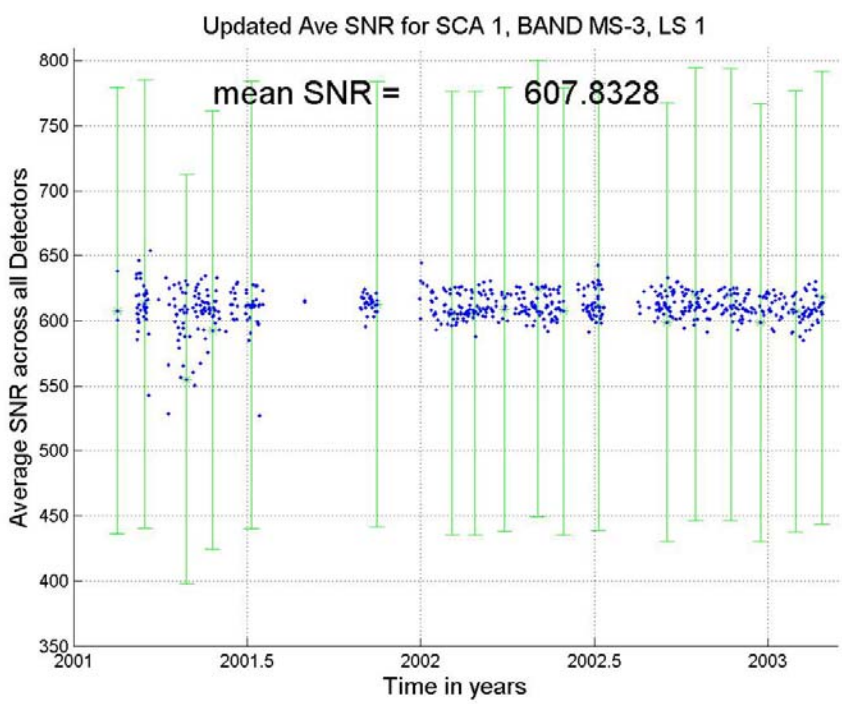

Figure A2d. Lifetime SNR, SCA 1 Band MS-3, LS 1

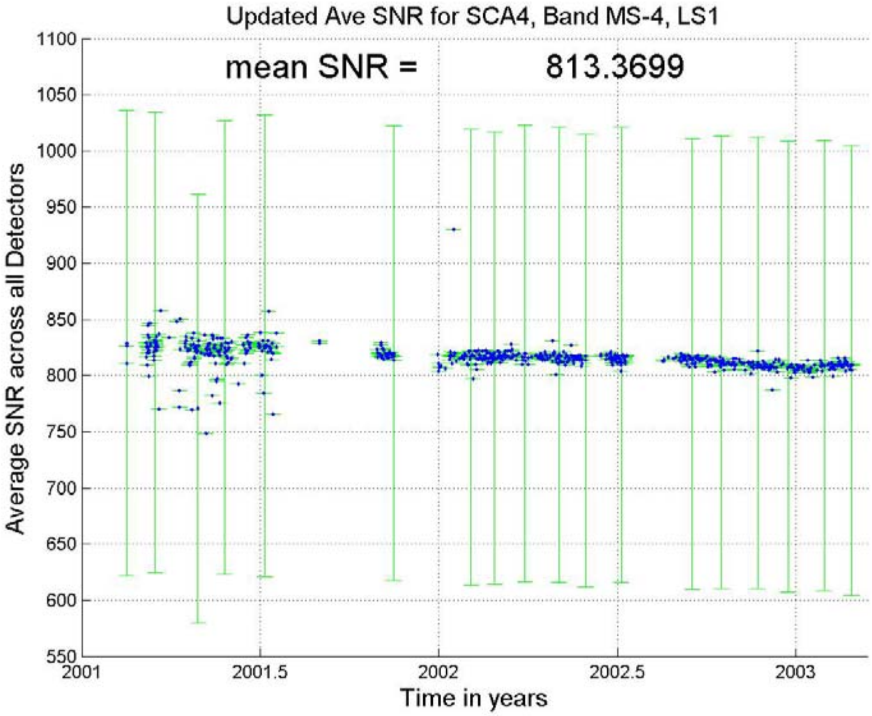

Figure A2e. Lifetime SNR, SCA 4 Band MS-4, LS 1

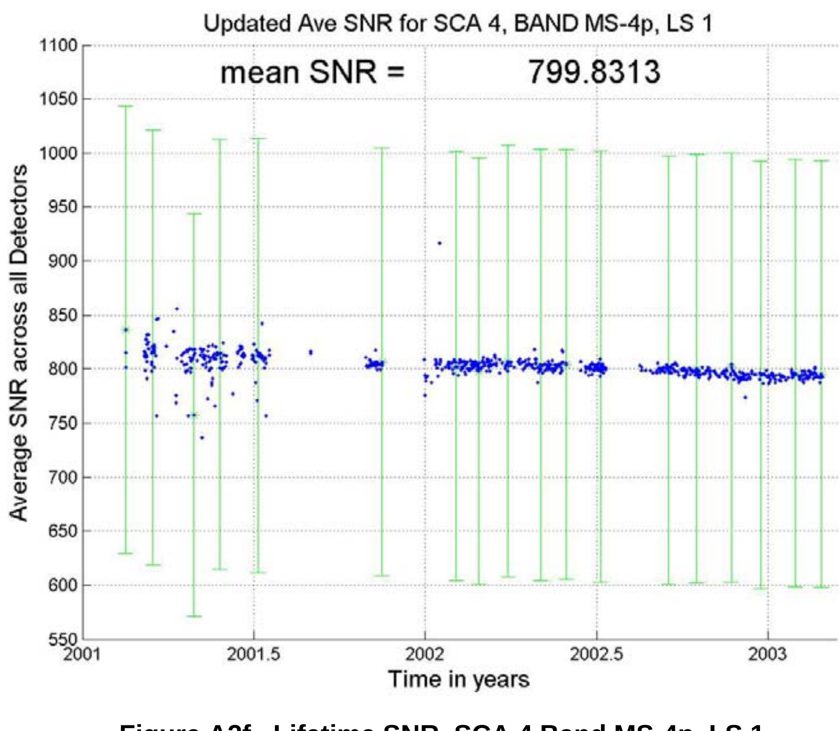

Figure A2f. Lifetime SNR, SCA 4 Band MS-4p, LS 1

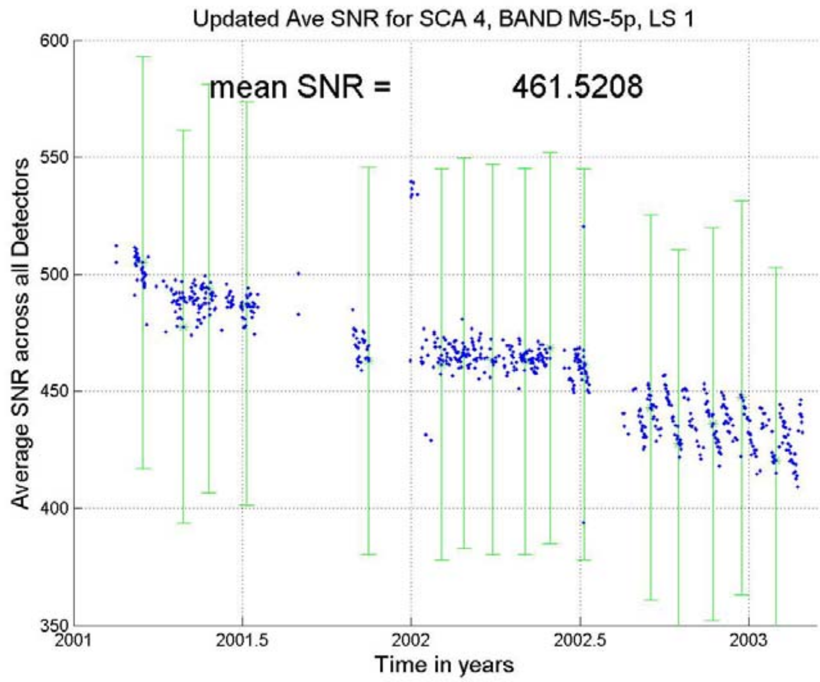

Figure A2g. Lifetime SNR, SCA 4 Band MS-5p, LS 1

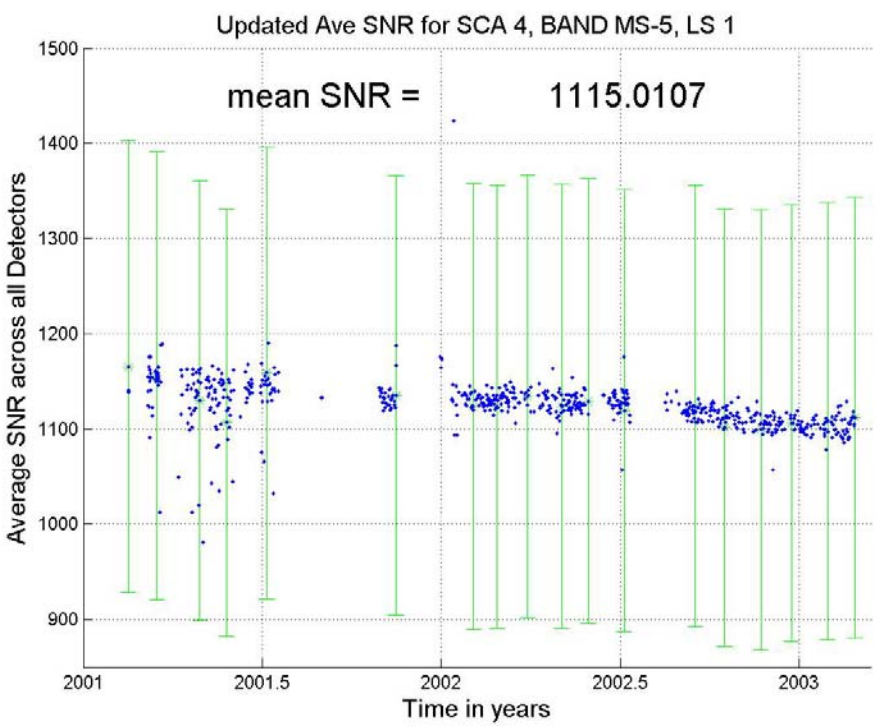

Figure A2h. Lifetime SNR, SCA 4 Band MS-5, LS 1

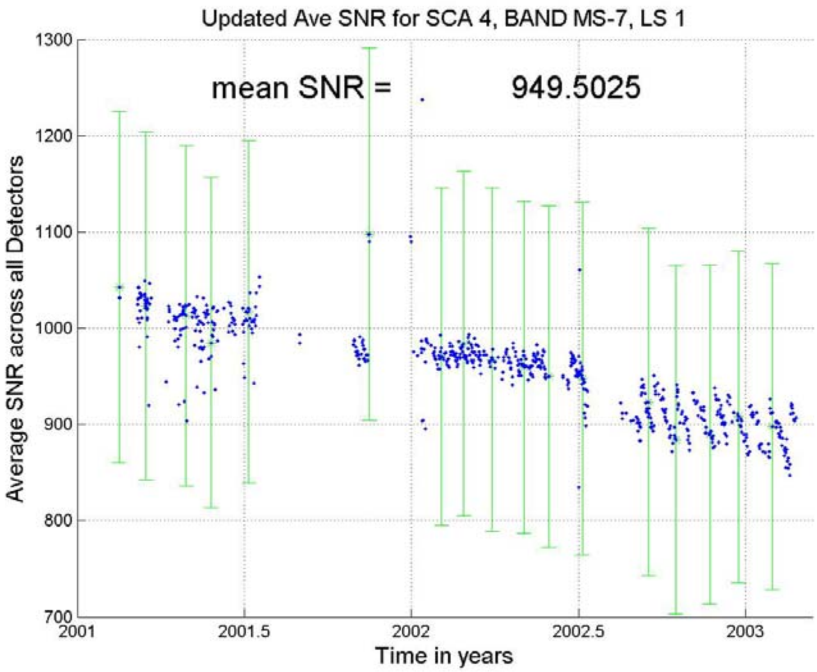

Figure A2i. Lifetime SNR, SCA 4 Band MS-7, LS 1